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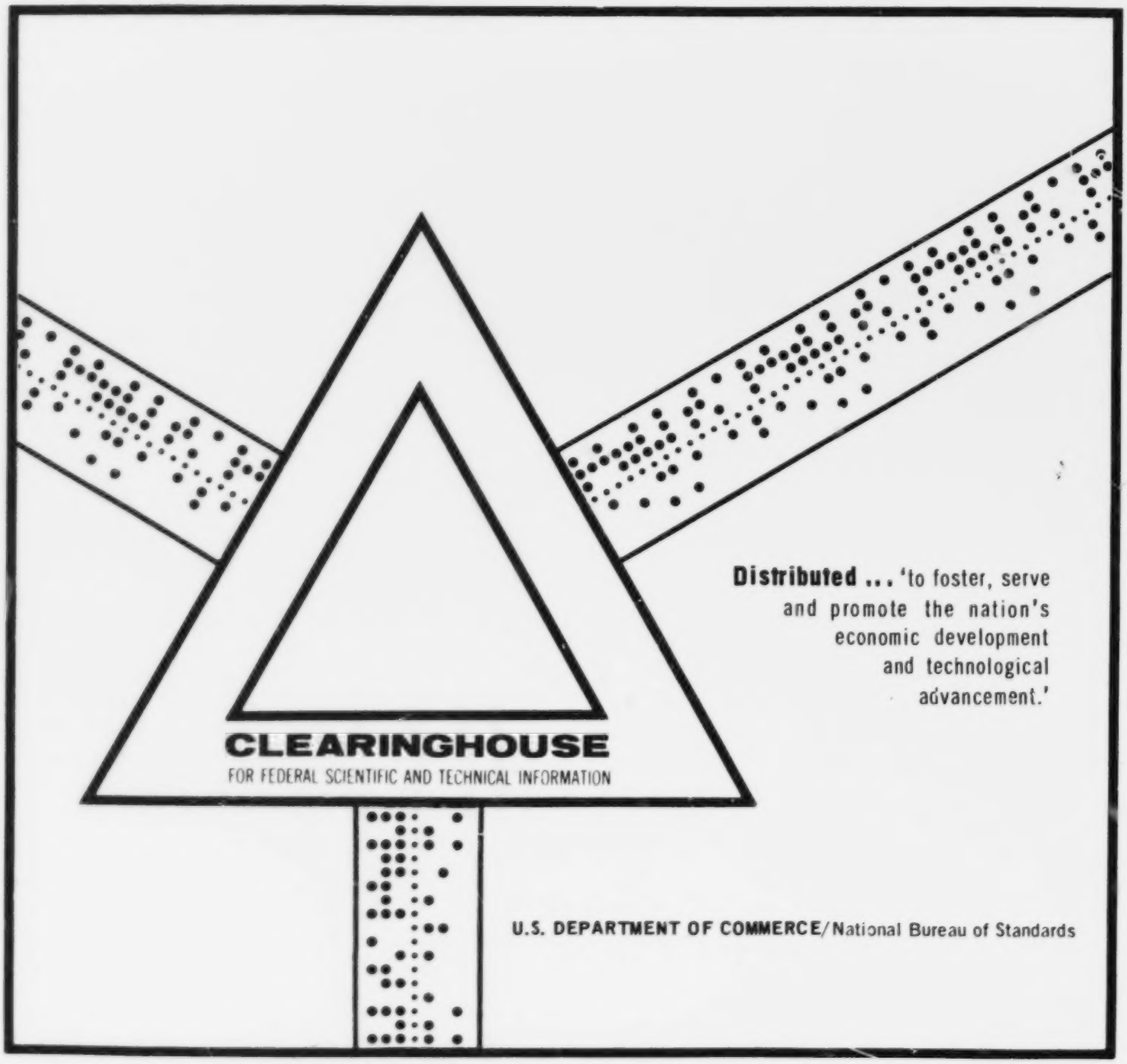
COMPILATION OF AIR POLLUTANT EMISSION FACTORS

R. L. Duprey

National Air Pollution Control Administration
Raleigh, North Carolina

1968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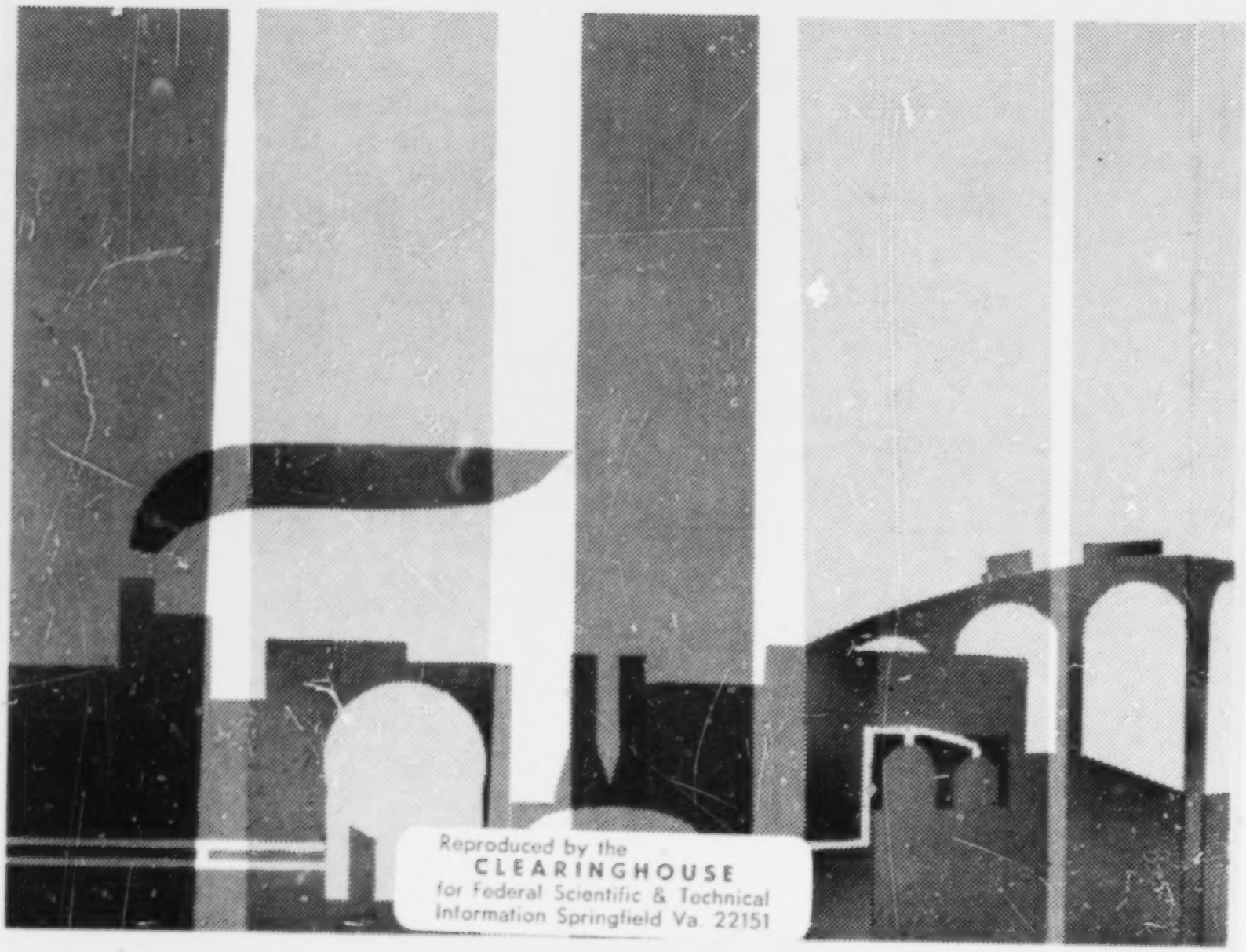

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S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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R. L. Duprey

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
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The ENVIRONMENTAL HEALTH SERIES of reports was established to report the results of scientific and engineering studies of man's environment: The community, whether urban, suburban, or rural, where he lives, works, and plays; the air, water and earth he uses and reuses; and the wastes he produces and must dispose of in a way that preserves these natural resources. This SERIES of reports provides for professional users a central source of information on the intramural research activities of the Centers in the Bureau of Disease Prevention and Environmental Control, and on their cooperative activities with State and local agencies, research institutions, and industrial organizations. The general subject area of each report is indicated by the letters that appear in the publication number; the indicators are

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PREFACE

This report is a compilation of emission factors developed primarily from technical literature resources and based upon a previous report on emission factors by M. Mayer entitled "A Compilation of Air Pollutant Emission Factors for Combustion Processes, Gasoline Evaporation, and Selected Industrial Processes," published by the U. S. Department of Health, Education and Welfare, Public Health Service, National Center for Air Pollution Control in May 1965.

Additional sources have been added to this report, and various revisions have been made in the previously published emission factors and in the format of the report. Consequently, this report supersedes the original publication on emission factors. As additional emission data become available in the literature, the present compilation will be revised to reflect the newer data and developments.

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COMPILATION OF AIR POLLUTANT EMISSION FACTORS

INTRODUCTION

Because of the diversity and complexity of the sources of air pollution, the atmospheres of our metropolitan areas contain numerous chemical substances and their derivatives or oxidation products. To assess the relative contribution of the sources of air pollution, the major types and quantities of pollutants emitted must be determined. Classification of contaminants involves first distinguishing between particulates, both liquid and solid, and gaseous emissions. The gaseous emissions may be further divided into organic and inorganic gases. The organic gases that are significant air contaminants are hydrocarbons, aldehydes and ketones, and organic acids. The primary air contaminants among the inorganic gases are oxides of nitrogen, oxides of sulfur, and carbon monoxide. Hydrogen sulfide, ammonia, chlorine, and hydrogen fluoride are other inorganic air contaminants considered in this report.

To assess the air pollution potential of these primary pollutants, an inventory of air pollution sources must be made. This inventory can be accomplished by the sampling and analysis of the effluent gases from industrial processes and combustion sources. From these data an "emission factor" can be developed. The emission factor is a statistical average of the rate at which pollutants are emitted from the burning or processing of a given quantity of material or on the basis of some other meaningful parameter such as the number of miles traveled in a vehicle.

The source emission factors presented in this report were compiled primarily for use in conducting an air pollutant emission inventory. In some cases, especially some industrial sources, the emission factor may be based upon tests conducted on only one installation or a few installations. The data are presented to be used in making estimations and, as such, should not be considered as exact. The emissions from a particular source may vary considerably, depending upon a number of factors including sampling technique, analytical method, and inherent differences in the process. The emission factors presented herein, however, are the most accurate currently available.

FUEL COMBUSTION

The burning of coal, fuel oil, and natural gas to produce power and heat is one of the most important sources of particulates and oxides of sulfur and nitrogen emissions to the atmosphere. Controls are available for particulates from coal-fired furnaces, but there are presently no commercially available control systems for oxides of nitrogen and sulfur from fuel combustion. The following sections present detailed emission data for the various types of fossil fuel furnaces and control systems.

COAL COMBUSTION

Coal is utilized primarily in power plants, industrial processes, and domestic and commercial space heating in a variety of furnaces. Particulate emission factors are presented in Table 1 for the various types of furnaces based on the quantity of coal burned. Particulates emitted from coal combustion consist primarily of carbon, silica, alumina, and iron oxide in the fly ash. Their specific gravities average about 2.5. The quantity of the particulate emission is dependent upon the ash content of the coal, the type of combustion unit, and the control equipment used. Table 2 presents the range of collection efficiencies for common types of fly ash control equipment. The section in the appendix on control equipment may also be used to calculate emissions from coal-fired furnaces using control equipment.

Gaseous emissions from coal combustion include aldehydes, carbon monoxide, hydrocarbons, nitrogen oxides, and sulfur oxides. The quantities of these pollutants are dependent upon the composition of the coal, type of combustion equipment, method of firing, size of the unit, and various other design and operational variables. Table 3 gives average emission factors for the gaseous pollutants in the three major categories of coal usage. As a rule of thumb, for these three categories, boiler capacities for power plants are generally above

Table 1. PARTICULATE EMISSION FACTORS FOR COAL COMBUSTION WITHOUT CONTROL EQUIPMENT[a]

Type of unit	Particulate per ton of coal burned[b], lb	Percent 44 microns or greater	Percent 20 to 44 microns	Percent 10 to 20 microns	Percent 5 to 10 microns	Percent less than 5 microns
Pulverized						
General	16 A	25	23	20	17	15
Dry bottom	17 A	25	23	20	17	15
Wet bottom without fly ash reinjection	13 A	25	23	20	17	15
Wet bottom with fly ash reinjection[c]	24 A	25	23	20	17	15
Cyclone	2 A	10	7	8	10	65
Spreader stoker -						
without fly ash reinjection	13 A	61	18	11	6	4
with fly ash reinjection[c]	20 A	61	18	11	6	4
All other stokers	5 A	70	16	8	4	2
Hand-fired equipment	20	--	--	--	--	100

[a]Reference 1.

[b]The letter A on all units other than hand-fired equipment indicates that the percent ash in the coal should be multiplied by the value given.
Example: If the factor is 17 and the ash content is 10 percent, the particulate emission before the control equipment would be 10 times 17, or 170 pounds of particulate per ton of coal.

[c]Values should not be used as emission factors. Values represent the loading reaching the control equipment always used on this type of furnace.

Table 2. RANGE OF COLLECTION EFFICIENCIES FOR COMMON TYPES OF FLY ASH CONTROL EQUIPMENT[a]

Type of furnace	Range of collection efficiencies, %			
	Electrostatic precipitator	High-efficiency cyclone	Low-resistance cyclone	Settling chamber expanded chimney bases
Cyclone furnace	65 - 99[b]	30 - 40	20 - 30	-
Pulverized unit	80 - 99.9[b]	65 - 75	40 - 60	-
Spreader stoker	-	85 - 90	70 - 80	20 - 30
Other stokers	-	90 - 95	75 - 85	25 - 50

[a]Reference 1.
[b]High values attained with high-efficiency cyclones in series with electrostatic precipitators.

Table 3. GASEOUS EMISSION FACTORS FOR COAL COMBUSTION[a]
(pounds per ton of coal burned)

Pollutant	Type of unit		
	Power plant	Industrial	Domestic and commercial
Aldehydes (HCHO)	0.005	0.005	0.005
Carbon monoxide	0.5	3	50
Hydrocarbons (CH_4)	0.2	1	10
Oxides of nitrogen (NO_2)	20	20	8
Oxides of sulfur (SO_2)	38S[b]	38S[b]	38S[b]

[a]Reference 1.
[b]S equals percent sulfur in coal, e.g., if sulfur content is 2 percent, the oxides of sulfur emission would be 2 x 38 or 76 pounds of sulfur oxides per ton of coal burned.

100×10^6 Btu per hour; industrial boilers are in the range of 10 to 100×10^6 Btu per hour; domestic and commercial boilers are below 10×10^6 Btu per hour capacity.

The emission factors presented can be converted to a Btu basis using the conversion factor of 26×10^6 Btu released per ton of coal burned.

GAS COMBUSTION

Natural gas is also utilized in power plants, industrial process heating, and space heating. Particulate and oxides of sulfur emissions are insignificant campared with other fossil fuels. Natural gas combustion, however, is a significant source of oxides of nitrogen. Table 4 presents particulate and gaseous emission factors for natural gas combustion. Particle size can be assumed to be less than 5 microns. The calculations are based upon a density for natural gas of 0.052 pound per standard cubic foot and a heating value of 1,000 Btu per standard cubic foot. Control equipment has not been utilized to control emissions from natural gas combustion equipment.

Table 4. EMISSION FACTORS FOR NATURAL GAS COMBUSTION[a]
(pounds per million cubic feet of natural gas burned)

Pollutant	Type of unit		
	Power plant	Industrial process boilers	Domestic and commercial heating units
Aldehydes (HCHO)	1	2	neg.
Carbon monoxide	neg.	0.4	0.4
Hydrocarbons	neg.	neg.	neg.
Oxides of nitrogen (NO_2)	390	214	116
Oxides of sulfur (SO_2)	0.4	0.4	0.4
Other organics	3	5	neg.
Particulate	15	18	19

[a]References 2 and 4.

FUEL OIL COMBUSTION

Fuel oil is the other major fossil fuel used in this country for power production, industrial process heating, and space heating. Fuel oil can be classified as distillate or residual. Distillate fuel oil is primarily a domestic fuel, but is used in some commercial and industrial applications where a higher quality oil is required.

Residual fuel is used in power plants and commercial and industrial applications. Residual fuel oil contains higher ash and sulfur content than distillate fuel oil and is more difficult to burn properly. Emissions from oil combustion are dependent on type of equipment,

size, and method of firing. Maintenance and operation are also critical. Table 5 gives emission factors for the major category users. Note that the commercial category is split into residual and distillate since there is a significant difference in particulate emissions from the same equipment depending on the fuel oil used. It should also be noted that power plants emit less particulate per quantity of oil consumed, reportedly because of better design and more precise operation of the equipment.

Table 5. EMISSION FACTORS FOR FUEL OIL COMBUSTION[a]
(pounds per 1,000 gallons of oil burned)

Pollutant	Type of unit			
	Power plant	Industrial and commercial		Domestic
		Residual	Distillate	
Aldehydes (HCHO)	0.6	2	2	2
Carbon monoxide	0.04	2	2	2
Hydrocarbons	3.2	2	2	3
Oxides of nitrogen (NO_2)	104	72	72	12
Sulfur dioxide	157S[b]	157S[b]	157S[b]	157S[b]
Sulfur trioxide	2.4S[b]	2S[b]	2S[b]	2S[b]
Particulate	10	23	15	8

[a] References 3, 4, 5, and 6.
[b] S equals percent sulfur in oil, e.g., if the sulfur content is 2 percent, the sulfur dioxide emission would be 2 x 157 or 314 pounds of sulfur dioxide per 1,000 gallons of oil burned.

Particulate emitted from fuel oil combustion consists of 10 to 30 percent ash, 17 to 25 percent sulfates, and 25 to 50 percent cenospheres formed during combustion. The particulate has a specific gravity of about 1.0 and is a granular hygroscopic material. Particle size distribution from oil-fired boilers is extremely variable. The most typical range is from less than 1 to 40 microns. From 10 to 99.5 percent by weight have been reported to be less than 5 microns. Essentially 100 percent of the particles are less than 44 microns. A typical figure of 50 percent by weight less than 5 microns is recommended for calculations.[3, 5]

REFUSE INCINERATION

Methods of refuse disposal in this country have included primarily incineration, sanitary land fill, and composting. Incineration, the most prominent means of disposal, ranges from large municipal multiple-chamber incinerators to small domestic contrivances. Open burning with no control over excess air or feed rate is also widely practiced. Many apartment houses use what is called the flue-fed incinerator for refuse disposal. Commercial and industrial establishments use single-or multiple-chamber incinerators to burn their wastes.

Particulate emission factors for uncontrolled incinerators are presented in Table 6. Table 7 gives collection efficiencies based on present technology for various devices used on incinerators. Particulates from incinerators burning municipal refuse consist primarily of fly ash containing carbon. Specific gravity of this material is about 2.0.[38] Research studies have shown that particulate emissions from incinerators are primarily dependent upon underfire air rate and fuel composition regardless of furnace size.[18] Particle size distribution data presented in Table 6 are based upon a number of tests conducted

Table 6. PARTICULATE EMISSION FACTORS FOR REFUSE INCINERATORS WITHOUT CONTROL

Type of unit	Particulate, lb/ton of refuse	Percent 44 microns or greater	Percent 20 to 44 microns	Percent 10 to 20 microns	Percent 5 to 10 microns	Percent less than 5 microns
Municipal incinerator[a] (multiple chamber)	17	40	20	15	10	15
Commercial incinerator[b] (multiple incinerator)	3	40	20	15	10	15
Commercial incinerator[c] (single chamber)	10	40	20	15	10	15
Flue-fed incinerator[d]	28	40	20	15	10	15
Domestic incinerator[e] (gas-fired)	15	40	20	15	10	15

[a] Includes settling chamber, references 7, 8, 9, 10, 11, 12, and 13.

[b] References 14, 15, 16, 17, 18, and 19.

[c] References 14, 16, 20, 21, 22, and 23.

[d] References 14, 24, 25, and 26.

[e] References 30 and 31.

Table 7. COLLECTION EFFICIENCY FOR VARIOUS TYPES OF INCINERATOR PARTICULATE CONTROL SYSTEMS

(percent)

Type of incinerator	Wetted baffles	Impingement scrubbers	Afterburners, draft control	Electrostatic precipitator	Baghouse
Municipal incinerator (multiple chamber)	60[a]	94[b]	-	94[c]	99[b]
Flue-fed incinerator	-	85[d]	75[e]	-	-
Domestic gas-fired	-	-	60[f]	-	-

[a]References 8, 9, 10, 12, 20, 23, and 34.

[b]Reference 35.

[c]Reference 15.

[d]References 26, 27, 28, and 29.

[e]References 24 and 26.

[f]References 30, 31, and 32.

on municipal incinerators and are applied as representing all incinerator fly ash since no data are available for other types of incinerators.

Gaseous emissions from incinerators are presented in Table 8. Nitrogen oxides, sulfur oxides, and ammonia are minor compared with other sources. Some types of incinerators emit significant quantities of organic material, including aldehydes, hydrocarbons, organic acids, and carbon monoxide.

Table 8. GASEOUS EMISSION FACTORS FOR REFUSE INCINERATORS

(pounds per ton of refuse)

Pollutant	Municipal incinerator	Industrial and commercial		Flue-fed		Domestic	
		Multiple chamber	Single chamber	No control	After-burner	No control	After-burner
Ammonia[a]	0.3	0.1	0.4	0.4	0.4	0.3	0.3
Aldehydes (HCHO)[b]	0.3	0.2	1	3	2	5.5	2.5
Carbon monoxide[c]	1	10	44	27	-	200	30
Hydrocarbons (hexane)[d]	0.3	0.5	0.8	2	-	2	1
Nitrogen oxides (NO_2)[e]	2	2	3	0.3	10	1	2
Organic acids (acetic)[f]	0.6	3	3	25	6	7	2
Sulfur oxides (SO_2)[g]	2	1	2	0.2	0.2	0.4	0.4

[a]References 19, 20, 30, 36, and 37.

[b]References 11, 12, 16, 17, 19, 20, 24, 25, 26, 30, 32, 36, and 37.

[c]References 11, 16, 18, 22, 25, 30, 33, and 37.

[d]References 11, 12, 16, 18, 19, 20, 22, 24, 30, 32, and 37.

[e]References 11, 12, 16, 18, 20, 23, 24, 25, 26, 30, and 36.

[f]References 19, 20, 24, 25, 26, 30, 36, 37, and 39.

[g]References 19, 20, 25, 26, 30, and 36.

Open burning is widely practiced, especially in rural areas. Table 9 gives emission factors for open burning of three general types of waste material. Both particulate and gaseous emissions are higher from open burning than they are from more efficient methods of incineration. These emissions were measured using equipment specifically designed to analyze open-burning effluents.[40] No particle size data are reported in the literature for open burning.

Table 9. EMISSION FACTORS FOR OPEN BURNING[a]
(pounds per ton of refuse)

Pollutant	Municipal refuse	Landscape and agriculture refuse[b]	Automobile components[c]
Particulate	16	17	100
Aldehydes (HCHO)	0.1	0.01	0.03
Carbon monoxide	85	60	125
Hydrocarbons (methane)	30	12	30
Nitrogen oxides (NO_2)	11	2	8
Organic acids (acetic)	15	13	16

[a]References 40, and 41.
[b]Factor can be used for leaves, grass, and various agriculture wastes such as barley, rice, cotton, fruit tree prunings, and brush.
[c]Includes tires, floor mats, and car seats.

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CHEMICAL PROCESS INDUSTRY

AMMONIA PLANT

The manufacture of ammonia from natural gas is a potential source of carbon monoxide and ammonia fumes. To produce 1 ton of ammonia, 26,000 cubic feet of natural gas is required. The process involves reforming natural gas with steam to hydrogen and carbon oxides. The carbon dioxide is removed by the amine absorption process. A mixture of nitrogen and hydrogen in a 1-to-3 ratio, carbon monoxide, argon, and unreacted methane is compressed to 2,000 pounds per square inch. The residual carbon dioxide and carbon monoxide are removed by absorption with an ammonical solution of copper formate. The process gas is then compressed to 5,000 pounds per square inch and catalytically reacted to produce ammonia.

The two possible sources of air pollution are the off-gas from the carbon monoxide absorber and the purge gas from the ammonia converters and ammonia storage tank vents. One 450-ton-per-day plant reports 1,200 standard cubic feet per minute (scfm) of 73 percent carbon monoxide and 4 percent ammonia emitted from the carbon monoxide absorber. At this rate of production 7 pounds of ammonia and 200 pounds of carbon monoxide are emitted per ton of ammonia produced. The ammonia is usually removed in packed scrubbers using water, and the carbon monoxide is utilized in the boiler furnaces as a supplementary fuel. The purge gas consists of about 2,000 scfm of 70 percent ammonia fumes, which is equivalent to 200 pounds ammonia per ton of ammonia produced. The ammonia is removed in a series of absorbers and recovered as product. Emissions amount to 0.2 pound per ton of ammonia produced after recovery.[43]

CHLORINE PLANT

Ninety-five percent of the chlorine manufactured in the United States is by the electrolysis of brine in either the mercury or diaphragm cell, which separate the caustic and gaseous chlorine. Hot-cell chlorine is then cooled and dried in sulfuric acid towers before

liquefaction and shipment by tank car or ton containers. Principal chlorine emissions stem from unliquefied vent gases, which may be sent to scrubbers for recovery or disposal. Table 10 presents emission factors for controlled and uncontrolled vent gases for major and minor sources.[44]

Table 10. EMISSIONS FROM CHLORINE MANUFACTURING[a]
(pounds per 100 tons of liquefied chlorine)

Source	Chlorine gas
Mercury cell plant - uncontrolled	4,000-16,000
Diaphragm cell plant - uncontrolled	2,000-10,000
Water absorber	400
Carbon tetrachloride absorber	90[b]
Sulfur monochloride	30
Caustic or lime scrubber	0.1
Tank car vents	450
Storage tank vents	1,200
Air-blowing of mercury cell brine	500
Mercury cells	1.5[c]

[a]Reference 44.

[b]CCl_4 loss.

[c]Loss of mercury to atmosphere.

Minor chlorine emissions may also be produced in liquid chlorine transfer operations, air-blowing of mercury cell brine, and from the cell room. These emissions may be controlled by ducting to the liquefaction vent gas scrubber or to a separate scrubber.

NITRIC ACID PLANT

The ammonia oxidation process is the principal method of producing commercial nitric acid. It involves high-temperature oxidation of ammonia with air over a platinum catalyst to form nitric oxide. The nitric oxide - air mixture is cooled, and additional air is added to complete the oxidation to nitrogen dioxide. The nitrogen dioxide is absorbed in water to produce an aqueous solution of nitric acid.

The primary pollutants are nitric oxide and nitrogen dioxide discharged from the water absorber to the atmosphere. Trace amounts of acid mist are also present, but are considered insignificant. Small amounts of nitrogen dioxide are also lost from the acid concentrators and storage tanks. Average emission from 12 uncontrolled plants is 57 pounds of nitrogen oxides, as NO_2, per ton of acid produced (100% basis). Emissions from nitric acid concentrators amount to about 10 pounds of nitrogen oxides, as NO_2, per 1,000 pounds of strong acid produced.[45] Plants using catalytic combustors to treat the tail gas from the absorber column expect a reduction of about 80 percent with a reported range of 36 to 99.8 percent. Alkaline scrubbers reportedly reduce nitrogen oxides by about 90 percent.[45]

PAINT AND VARNISH MANUFACTURING

Protective coating manufacturing may include processing natural or synthetic oils, resins, pigments, solvents, plasticizers, metallic soaps, or antioxidants. A major component of coatings is the oil or resin. The manufacture depends on subjecting complex organic materials to elevated temperatures. During this cooking the basic constituents decompose and release contaminants to the atmosphere. Losses depend on composition of mix, rate of heating, maximum temperature, stirring, method of additive addition, type and extent of blowing, and length of cooking.

Varnish cooking fume losses average 3 to 6 percent of the feed; alkyresin production, 4 to 6 percent; cooking and blowing of oils, 1 to 3 percent; and heat polymerization, 1 percent of the feed for uncontrolled sources.[47] Composition of the fume consists of organics such as aldehydes, ketones, phenols, terpenes, and glycerine. Particle size ranges from 2 to 20 microns.[46] Scrubbing, incineration, and catalytic combustion have been used as control methods. An impingement-type water scrubber reportedly reduced emissions by about 90 percent.[47] A catalytic afterburner reduced emissions from a varnish cooker by about 85 percent.[48] Direct flame afterburners achieve better than 90 percent reduction in fume emissions.[46]

PHOSPHORIC ACID PLANT

Phosphoric (orthophosphoric) acid is produced by two principal methods, the wet process and the thermal process. The wet process is usually employed when the acid is to be used for fertilizer production. Thermal-process acid is normally of higher purity and is used in the manufacture of high-grade chemical and food products.

In the wet process, sulfuric acid and phosphate rock are reacted in agitated tanks to form phosphoric acid and gypsum. Phosphoric acid is separated from the gypsum and other insolubles by vacuum filtration. Usually there is little market value for the gypsum. The phosphoric acid is normally concentrated from 50 to 55 percent P_2O_5 by evaporation. When superphosphoric acid is made, the acid is concentrated to between 70 and 85 percent P_2O_5. Emission of gaseous fluorides, consisting mostly of silicon tetrafluoride with some hydrogen fluoride, ranges from 20 to 60 pounds per ton of P_2O_5 produced.[49]

In the thermal process, phosphate rock, siliceous flux, and coke are heated in an electric furnace to produce elemental phosphorous. The gases containing the phosphorous vapors are passed through an electrical precipitator to remove entrained dust. In the "one-step" version of the process, the gases are next mixed with air to form P_2O_5 before passing to a water scrubber (packed tower) to form phosphoric acid. In the "two-step" version of the process, the phosphorous is condensed and pumped to a tower in which it is burned with air, and the P_2O_5 formed is hydrated by a water spray in the lower portion of the tower.

The principal air contaminant from thermal-process phosphoric acid manufacturing is P_2O_5 acid mist from the absorber tail gas. Trace quantities of nitrogen oxides are also emitted. All plants are equipped with some type of acid mist collection system. Table 11 presents acid mist emission data for the various types of control systems. The particle size of the acid mist ranges from 0.4 to 2.6 microns, with a mass median diameter of 1.6 microns.[50]

Table 11. ACID MIST EMISSIONS FROM THERMAL PROCESS PHOSPHORIC ACID[a]

(pounds per tons of phosphorus burned)

Collector	Emission
Packed tower	4.6
Packed tower plus wire-mesh mist eliminator	7.0
Scrubber plus wire-mesh mist eliminator	4.4
Cyclonic separator plus wire-mesh mist eliminator	8.6
Venturi scrubber plus wire-mesh mist eliminator	10.8
Venturi scrubber	5.6
Glass-fiber mist eliminator	3.0
Wire-mesh mist eliminator	2.7
High-pressure-drop wire-mesh mist eliminator	0.2
Venturi scrubber, cyclonic separator, and wire-mesh mist eliminator	1.8
Electrostatic precipitator	1.8

[a]Reference 50.

PHTHALIC ANHYDRIDE PLANT

Phthalic anhydride is principally produced by oxidizing napthalene vapors with excess air over a catalyst. The resulting gas stream is cooled, and the phthalic anhydride condenses. The excess air containing some uncondensed phthalic anhydride, maleic anhydride, quinines, and other organics is vented to the atmosphere. To produce 1 ton of phthalic anhydride, 2,500 pounds of napthalene and 830,000 scfm of air are required.[42]

Organic emissions (as hexane) from phthalic anhydride plants is reported as 32 pounds per ton of phthalic anhydride produced.[48] Control with catalytic combustion can reduce this emission by 65 percent.

SULPHURIC ACID PLANT

In the United States, sulfuric acid is produced mainly by the contact process. Elemental sulfur or sulfur-bearing materials are burned in clean air that has been dried by scrubbing with sulfuric acid.

Among the sulfur-bearing materials used are iron pyrites, spent acid and hydrogen sulfide from refinery operations, and smelter off-gases. The sulfur dioxide produced is further oxidized to sulfur trioxide in the presence of a vanadium pentoxide catalyst. The sulfur trioxide is then contacted with 98 to 99 percent sulfuric acid to produce a more concentrated acid. The principal emissions are sulfur dioxide and sulfuric acid mist.[51]

The emissions of sulfur dioxide range from about 20 to 70 pounds of sulfur dioxide per ton of acid produced and are unaffected by the presence of acid mist eliminators. Without acid mist eliminators, emissions of acid mist range from 0.3 to 7.5 pounds of acid mist per ton of acid produced. The use of acid mist eliminators reduces this emission to some 0.02 to 0.2 pound of acid mist per ton of acid produced.[52] About 98 percent of the acid mist particles from a commercial contact sulfuric acid plant have been reported to be less than 3 microns.[53]

FOOD AND AGRICULTURAL INDUSTRY

The volume of production of this industry makes it worth investigating as a source of air pollutants. Dust and odors are the most prevalent contaminant emissions from this industry. Only those sources for which there is quantitative emission data are included herein.

ALFALFA DEHYDRATING PLANT

This type of plant produces an animal feed from alfalfa. The initial step of drying the alfalfa is usually done in a rotary duct-fired drier. The dried material is pneumatically conveyed to a primary cyclone, where heavy trash is removed. A second cyclone discharges material to the grinding equipment, which is usually a hammer mill. The ground material is collected in an air-meal separator. The alfalfa meal may then be conveyed directly to bagging or storage, pelletized, or blended with other ingredients.

Sources of dust emissions are the primary cyclone and the air-meal separators. Total loss of product to atmosphere is 1 to 3.5 percent by weight of meal production. The use of a baghouse as a secondary collection system can reduce emissions to 0.005 percent of product. Average particle size varies from 1.5 to 10 microns.[54]

COFFEE ROASTING PLANT

Coffee, which is imported in the form of green beans, must be cleaned, blended, roasted, and packaged before it is sold to the consumer. The essential ingredients of the roasted beans may be extracted, spray-dried, and marketed as instant coffee. In the roasting of coffee, chemical changes, such as a degradation of sugars, bring out the characteristic flavor and aroma of the coffee. In the indirect-fired roaster, a portion of the roaster gases is recirculated through the combustion area for destruction of smoke and odors by oxidation in the flame. In the direct-fired roaster, gases are vented without recirculation through the flame. Essentially complete removal of

both smoke and odors can be realized with a properly designed afterburner. In the cleaner, contaminating materials lighter than the green beans are separated from the beans by an air stream. In the stoner contaminating materials heavier than the roasted beans are also separated from the beans by an air stream. In the cooler, quenching the hot roasted beans with water causes emission of large quantities of steam and some particulate matter.[55] Table 12 summarizes the emissions from the various operations involved in coffee processing.

Table 12. PARTICULATE EMISSIONS FROM COFFEE ROASTING PROCESSES[a]
(pounds per ton of green beans)

Process	Uncontrolled	Cyclone
Roaster		
Direct fired	7.6	2.2
Indirect fired	4.2	1.2
Stoner and cooler	1.4	0.4
Instant coffee spray drier	-	1.4[b]

[a]Reference 55.

[b]Cyclone plus wet scrubber (control always employed).

COTTON GINNING PROCESS

The primary emissions of air pollutants are trash, dust, and lint from cotton gins and particulates from incineration of cotton trash. Total particulate discharge from the cotton ginning operation has been reported as 11.7 pounds per 500-pound bale of cotton. About 60 percent of the particles were less than 100 microns.[56, 57]

FEED AND GRAIN MILLS

Dust emissions from feed and grain mills occur from the feed manufacturing process and the receiving, handling, and storage operations. The common grains are wheat, barley, corn, oats, rye, flax, and soybeans. Typical operations in feed manufacturing are cleaning, rolling, grinding, and blending. The primary source of dust emissions is the cleaning operation, which removes the chaff and dirt before the grain is processed. Receiving, handling, and storage operations contribute dust emissions from loading and unloading of trucks, rail cars, and ships. Other lesser sources of dust emission are conveying belts and storage bins.[58]

Overall dust emissions from feed and grain operations have been estimated as 0.3 percent of the material produced in a process employing cyclones with 90 percent collection efficiency.[59] Other emission factors for specific operations in feed and grain mills are included in Table 13. One test for particle size distribution of grain dust indicates 92 percent less than 44 microns, 34 percent 20 to 44 microns, 14 percent 10 to 20 microns, 11 percent 5 to 10 microns, and 3 percent less than 5 microns, all by weight determination. Specific gravity was 1.54.[61]

Table 13. PARTICULATE EMISSION FACTORS FOR FEED AND GRAIN MILL OPERATIONS[a]
(pounds per ton of product)

Operation	Collector	Particulate emission
Wheat air cleaner (chaff-free)	Cyclone	0.2
Alfalfa meal mill	Settling chamber and cyclone	4.0
Barley flour mill	Cyclone	3.1
Orange pulp dryer	Cyclone	11.3

[a]Reference 60.

FISH MEAL PROCESSING

The conventional fish rendering process involves cooking and pressing the fish, separating the oil from the aqueous fraction of the squeezing, concentrating the aqueous fraction by evaporation, drying the meal, and storing the various liquids and slurries. The principal odorous gases generated during the cooking process are hydrogen sulfide and trimethylamine. Emission factors for these pollutants are included in Table 14.

Table 14. EMISSION FACTORS FOR FISH MEAL PROCESSING[a]
(pounds per ton of fish meal produced)

Pollutant	Fresh fish	Stale fish
Trimethylamine	0.32	3.5
Hydrogen sulfide	0.01	0.2

[a]Reference 62.

STARCH MANUFACTURING PLANT

The manufacture of starch from corn can result in significant dust emissions. In one particular instance starch particles were collected from 35,000 scfm of gases coming from a natural-gas direct-fired flash drier producing 9.1 tons per hour of starch. Uncontrolled starch particle emissions were 8 pounds per ton of starch produced. A centrifugal gas scrubber reportedly reduced emissions to 0.02 pound per ton of product starch.[63]

METALLURGICAL INDUSTRY

The metallurigical industry has been traditionally one of the primary sources of particulate and sulfur oxide emissions to the atmosphere. As a result, control technology has been developed for controlling emissions from the metals industry. This section is divided into the primary and the secondary metals industry. The primary metals refer to production of the metal from ore. The secondary metals industry includes recovery of the metal from scrap and salvage and production of alloys from ingot. Unfortunately, except for steel, few quantitative data on emissions are available for primary metals production. Emissions from secondary metals operations have been well established from exhaustive tests in Los Angeles County, California.

PRIMARY METALS INDUSTRY

Aluminum Ore Reduction

Two processes are involved in the present-day production of aluminum. The Bayer process produces pure alumina from bauxite ore. The Hall-Heroult process, which reduces the alumina to metallic aluminum, uses an electrolytic cell, commonly known as a pot, consisting of molten cryolite and other fluoride salts operating at high temperature to dissolve the alumina. Four tons of bauxite is required to make 2 tons of alumina, which yields 1 ton of metallic aluminum. To produce 1 ton of aluminum, 16,000 kwh of electricity is required.[64]

During the pot reduction process, the effluent released contains some fluoride particulate and gaseous hydrogen fluoride. Particulate matter such as alumina and carbon from the anodes are also emitted. The fluoride particles range from 0.05 to 0.75 micron. About 50 percent of the fluorides are gaseous and 50 percent particulate. Course particulate emissions, other than fluorides, have been reported as about 300 pounds per day from an uncontrolled pot furnace.[64] No actual data on fluoride emissions are available, but from the consumption data on cryolite and other fluoride-containing ingredients

an estimated 75 to 85 pounds of fluoride, as fluorine, is emitted per ton of aluminum produced from an uncontrolled process.[47]

Copper Smelters

The primary production of copper in the United States is from low-grade sulfide ores, which are concentrated by gravity and flotation methods. Copper is recovered from the concentrate by four steps: roasting, smelting, converting, and refining. The roasting process removes the sulfur and calcines the ore in preparation for smelting in a reverberatory furnace. Multiple-hearth roasting is the most common. Smelting removes other impurities as a slag with the aid of fluxes. The matte that results from smelting is blown with air to remove the sulfur as sulfur dioxide. The end product is a crude metallic copper. A refining process further purifies the metal by air-blowing and slagging in reverberatory furnaces.

These four major processes emit carbon monoxide, sulfur oxides, nitrogen oxides, and a fine particulate fume. Sulfur dioxide emission is about 1400 pounds per ton of concentrated ore.[65] No quantitative information on other emissions was found in the literature.

Iron and Steel Mills

To make steel, iron ore (containing some 60 percent iron oxides) is reduced to pig iron, and some of its impurities are removed in a blast furnace. The pig iron is further purified in open hearths, Bessemer converters, the basic oxygen process furnace, or electric furnaces. Various alloying metals (chromium, manganese, etc.) are usually added to produce specialized types of steel.

Blast furnaces are charged with iron ore, coke, and limestone in alternating layers. To promote combustion, hot air is blown into the bottom of the furnace. To produce 1 ton of pig iron requires, on the average, 1.7 tons of iron ore; 0.9 ton of coke; 0.4 ton of limestone; 0.2 ton of cinder , scale, and scrap; and 4.0 to 4.5 tons of air.

Most of the coke used in the blast furnaces is produced in "by-product" coke ovens from certain grades of bituminous coal. The distillation products produced are recovered for sale, and gases remaining after by-product recovery are used for heating the coke

ovens and for other applications elsewhere in the plant. The hydrogen sulfide gas recovered is usually burned to sulfur dioxide and released to the atmosphere. Smoke and gases escape during charging, discharging, and quenching operations; the rest of the process is normally enclosed, but at some plants leakage of smoke and gases occurs because of poorly fitted oven doors.

Sintering plants convert iron ore fines and blast furnace flue dust into products more suitable for charging to the blast furnace. This is done by applying heat to a mixture of the iron-containing materials and coke or other fuels on a slow-moving grate through which combustion air is drawn.

In the open-hearth process for making steel, a mixture of scrap iron, steel, and pig iron is melted in a shallow rectangular basin, or "hearth," in which various liquid or gaseous fuels provide the heat. Impurities are removed in a slag. Oxygen injection (lancing) into the furnace speeds the refining processes, saves fuel, and increases steel production. Oxygen lancing increases the amount of fume and dust produced also.

The basic oxygen process, the LD or Linz-Donawitz process, is new to the United States, but is gaining increasing application here. In this process, oxygen blown at high velocity onto the surface of the molten bath causes violent agitation and intimate mixing of the oxygen with the pig iron. Electric furnaces are used primarily to produce special alloy steels. Heat is furnished by direct-arc-type electrodes extending through the roof of the furnace. In recent years oxygen has been used to increase the rate and uniformity of scrap meltdown and to decrease power consumption. Bessemer converters are no longer used extensively. They are pear-shaped, tilting, steel vessels lined with refractory brick and clay. Impurities in the molten iron charge are oxidized by air blown through the metal for about 15 minutes. A scarfing machine removes surface defects from the steel billets and slabs before they are shaped or rolled. This is done by applying jets of oxygen to the surface of the steel and thus removing a thin upper layer of the metal by rapid oxidation.[66]

Table 15 represents particle size distribution data for the various steel mill operations. Emission factors are given in Table 16.

Table 15. PARTICLE SIZE DISTRIBUTION FROM STEEL MILL OPERATIONS[a]

Operation	Specific gravity	Percent 44 microns and larger	Percent 20 to 44 microns	Percent 10 to 20 microns	Percent 5 to 10 microns	Percent less than 5 microns
Sintering	--	85	15	15	--	--
Blast furnace	--	68	--	--	--	--
Open-hearth furnace	5	5	20	17	22	46
Electric furnace	4	14.5	14.5	8	7.5	70
Basic oxygen furnace	--	--	--	--	0.5	99.5
Bessemer converter	--	--	100	--	--	--

[a]Reference 66.

Lead Smelters

The ore from which primary lead is produced contains both lead and zinc. Thus both a lead and zinc concentrate are made by concentration and differential flotation from ore. If substantial impurities remain, the lead concentrate is roasted in multiple reverberatory hearth roasters in which sulfur is removed and lead oxide is formed. The concentrate is then sintered on a hearth to remove additional sulfur and prepare a suitable material for the blast furnace. In one case sulfur was reduced from 9 to 3 percent by weight. The lead sinter, coke, and flux (usually limestone) are fed to the blast furnace, in which oxide is reduced to metallic lead. The lead may be further refined by a variety of other processes.[51]

Effluent gases from the roasting, sintering, and smelting operation contain considerable particulate matter and sulfur dioxide. One plant reportedly recovers 300 tons per day of lead dust from 800,000 scfm of gases using two parallel baghouses.[68] Sulfur dioxide emissions have been calculated to be about 660 pounds per ton of concentrated ore for plants without sulfur recovery units.[65]

Zinc Smelters

As stated previously, most domestic zinc comes from zinc and lead ores. The concentrated zinc ore is roasted to remove sulfur as

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Table 16. EMISSIONS FROM STEEL MILLS[a]

Operation	Before control		With control				Approximate volume of gases handled
	Stack loading, grains/scf	Pounds per ton of product	Control used[b]	Stack loading, grains/scf	Pounds per ton of product	Approximate efficiency, %	
Blast furnace	7-10	200	Preliminary cleaner (settling chamber or dry cyclone)[c]	3-6	-	60	87,000 scfm for 1000-ton-per-day furnace
			Primary cleaner (wet scrubber)[c]	0.05-0.3-0.7[d]	5.4	90	
			Secondary cleaner (E.S.P. or V.S.)[c]	0.004-0.008	0.1-1.4	90	
Sintering machine	0.5-3.0	5-20-100	Dry cyclone	0.2-0.6	2.0	90	120,000-160,000 scfm for a 1000-ton-per-day machine
			E.S.P. (in series with dry cyclone)	0.01-0.05	1.0	95	
Sinter machine discharge - crusher, screener, and cooler	6.0	22	Dry cyclone	0.4	1.5	93	17,500 scfm for a 1000-ton-per-day machine
Open hearth (not oxygen lanced)	0.1-0.4-2.0	1.5-7.5-20.0	E.S.P.	0.01-0.05	0.15	98	35,000 scfm for a 175-ton furnace
			V.S.	0.01-0.06	0.15-1.1	85-98	
			Baghouse	0.01	0.07	99	
Open hearth (with oxygen lance)	0.1-0.6-2.5	9.3	E.S.P.	0.01-0.05	0.2	98	35,000 scfm for a 175-ton furnace
			V.S.	0.01-0.06	0.2-1.4	85-98	
Electric arc furnace	0.1-0.4-6.0	4.5-10.6-37.8	High-efficiency scrubber	0.01	0.2	Up to 98	Highly variable depending on type of hood May be about 30,000 scfm for a 50-ton furnace
			E.S.P.	0.01-0.04	0.3-0.8	92-97	
			Baghouse	0.01	0.1-0.2	98-99	
Basic oxygen furnace	5.8	20-40-60	V.S.	0.03-0.12	0.4	99	Varies with amount of oxygen blown - 20 to 25 scfm per cfm of oxygen blown
			E.S.P.	0.05	0.4	99	
Scarfing machine	0.2-0.8	3 lb/ton of steel	Settling chamber	No data	No data	No data	85,000 scfm for 45-in., 4-side machine
Coke ovens (by-product type)	No data	0.1% of coal processed (rough estimate)	Emissions can be minimized through equipment design and operational techniques	No data	No data	No data	No data

[a]References 66 and 67.

[b]V.S. means venturi scrubber; E.S.P. means electrostatic precipitator.

[c]Used in series. Data on that basis.

[d]When three values are given, such as 5-20-100, the center value is the approximate average and values at either end are the lowest and highest values reported. All data are highly variable, depending on nature of a specific piece of equipment, materials being processed, and operating procedure.

sulfur dioxide. Metallic zinc can be produced from the roasted ore by the horizontal or vertical retort process, electrolytic process, or fractional distillation.[51]

No data are available on the particulates from these processes. Sulfur dioxide emissions have been calculated as 1090 pounds per ton of concentrated ore for smelters without sulfur recovery units.[65]

SECONDARY METALS INDUSTRY

The secondary metals industry includes smelters recovering metals from scrap as well as foundries involved in producing castings from melting ingots and scrap metals. Ferrous foundries include gray iron and steel casting. The principal nonferrous foundries include casting aluminum, brass, bronze, lead, magnesium, and zinc. The principal air contaminant is particulate matter consisting of smoke, dust, and metallic fumes characterized by their small particle size. Table 17 presents typical particle size distribution data for secondary metal processing. Control of these emissions requires highly efficient collection equipment such as baghouses, electrostatic precipitators, and high-pressure-drop scrubbers. Table 18 presents emission factors for operations common to all foundries including sand handling, production of cores, and core oven emissions. Approximately 5 pounds of sand is required per pound of metal cast.[69]

Table 17. PARTICLE SIZE DISTRIBUTION FROM SECONDARY METAL MELTING OPERATIONS[a]

Operation	Percent 44 microns or greater	Percent 20 to 44 microns	Percent 10 to 20 microns	Percent 5 to 10 microns	Percent less than 5 microns
Aluminum smelting	3	10	23	30	34
Brass smelting	-	-	-	-	100
Bronze smelting	-	-	-	-	100
Gray iron cupola	48	14	12	8	18
Lead smelting	-	-	2	3	95
Steel electric arc	4	8	12	16	60
Steel open hearth	6	10	10	12	62
Zinc smelting	-	-	-	-	100

[a]References 69, 70, 71, and 72.

Table 18. PARTICULATE EMISSION FACTORS FOR MISCELLANEOUS FOUNDRY OPERATIONS[a]

Operation	Particulate emission
Foundry sand handling	0.3 lb/ton of sand
Core ovens	0.3 lb/gal of core oil
Shell core machine	0.35 lb/ton of cores

[a]Reference 75.

Aluminum Operations

Secondary aluminum operations involve making lightweight metal alloys for industrial castings and ingots. Copper, magnesium, and silicon are the most common alloying constituents. Aluminum alloys for castings are melted in small crucible furnaces. Larger melting operations use open-hearth reverberatory furnaces. Small operators sometimes use sweating furnaces to treat dirty scrap in preparation for smelting. To produce a high-quality aluminum product, fluxing is practiced to some extent in all secondary aluminum melting. Aluminum fluxes are expected to remove dissolved gases and oxide particles from the molten bath. Various mixtures of potassium or sodium chloride with cryolite and chlorides of aluminum, zinc, and sodium are used as fluxes. Chlorine gas is usually lanced into the molten bath to reduce the magnesium content of the aluminum. The chlorine reacts to form magnesium and aluminum chlorides.[73,74]

Emissions include fine particulate matter and small quantities of gaseous chloride and fluorides. Table 19 presents particulate emission factors for secondary aluminum operations.[75]

Table 19. PARTICULATE EMISSION FACTORS FOR SECONDARY ALUMINUM OPERATIONS[a]
(pounds per ton of metal processed)

Operation	Uncontrolled	Baghouse	Electrostatic precipitator
Chlorination station	1000[b]	50.0	-
Crucible furnace	1.9	-	-
Reverberatory furnace	4.3	1.3	1.3
Sweating furnace	14.5	3.3	-

[a]Reference 75.

[b]Pounds per ton of chlorine used.

Brass and Bronze Smelting

Brass, an alloy of copper and zinc, may contain up to 40 percent zinc. Bronze is normally an alloy of copper and tin, but the bronzes referred to here contain lead and/or zinc. Brass and bronze may be melted in crucible, electric reverberatory, or rotary furnaces. Particulate emissions consist primarily of zinc oxide fumes. Table 20 gives emission factors for controlled and uncontrolled furnaces.

Table 20. PARTICULATE EMISSION FACTORS FOR BRASS AND BRONZE MELTING FURNACES[a]

(pounds per ton of metal charged)

Furnace	Uncontrolled	Baghouse
Crucible furnace	3.9	0.7
Electric furnace	3.0	0.6
Reverberatory furnace	26.3	1.8
Rotary furnace	20.9	1.5

[a]Reference 75.

Gray Iron Foundry

Three types of furnaces are used to produce gray iron castings. These include the cupola, electric induction, and reverberatory furnace. Table 21 presents particulate emission factors for gray iron cupolas and the other foundry furnaces. Gray iron cupolas also emit about 250 pounds of carbon monoxide per ton of charge. A well-designed afterburner can reduce this emission to 8 pounds per ton of charge.[75]

Table 21. PARTICULATE EMISSION FACTORS FOR GRAY IRON CUPOLAS[a]

(pounds per ton of metal charged)

Method of control	Particulate emissions
Uncontrolled	17.4
Wet cap	8
Impingement scrubber	5
High-energy scrubber (>60 inch H_2O)	3
Electrostatic precipitator	2.7
Baghouse	2.2
Reverberatory furnace	2.0
Electric induction furnace	2.0

[a]References 69, 75, 76, and 77.

Lead Smelting

Smelting of lead is accomplished in cupola, pot, and reverberatory furnaces. Sweating furnaces are used to reclaim lead from batteries and metal for printing type. The other furnaces are used to produce various lead alloys. Lead furnaces can be a significant source of particulate and sulfur emissions, as shown in Table 22. Control of particulate is usually by the use of baghouses.[68]

Table 22. EMISSION FACTORS FOR LEAD FURNACES[a]
(pounds per ton of metal charged)

Type of furnace	Uncontrolled		Baghouse	
	Particulate emissions	Sulfur compounds	Particulate emissions	Sulfur compounds
Cupola	300	64	5.1	58
Pot furnace	0.1	--	--	--
Reverberatory and sweating furnace	154	149	1.4	129

[a]Reference 75.

Magnesium Melting

Magnesium is generally melted in small pot furnaces to manufacture castings. A particulate emission factor of 4.4 pounds per ton of charge has been reported. No control equipment is used.[75]

Steel Foundry

Secondary processing of steel is accomplished in electric arc, electric induction, and open-hearth furnaces. Table 23 gives emission factors for controlled and uncontrolled furnaces.

Table 23. PARTICULATE EMISSION FACTORS FOR SECONDARY STEEL FURNACES[a]
(pounds per ton of steel charged)

Type of furnace	Uncontrolled	Baghouse	Electrostatic precipitator
Electric arc	15	1.4	--
Electric induction	0.1	--	--
Open hearth	10.6	--	0.5

[a]Reference 75.

Zinc Processes

The secondary processing of zinc includes zinc galvanizing, zinc calcining, and zinc smelting and sweating. Table 24 gives particulate emission factors for these operations.

Table 24. PARTICULATE EMISSION FACTORS FOR SECONDARY ZINC PROCESSES[a]
(pounds per ton of zinc charged)

Operation	Uncontrolled	Baghouse
Zinc galvanizing kettles	5.3	--
Zinc calcine kiln	88.8	1.0
Zinc pot furnace	0.1	--
Zinc sweating furnace	10.8	0.4

[a]Reference 75.

MINERAL PRODUCTS INDUSTRY

Mineral industries include the processing of nonmetallic substances such as glass, rock, clay, and various other materials. The principal air contaminants from these operations are particulates. The following sections detail the nature of these industries and their contaminant emissions to the atmosphere.

ASPHALT ROOFING MANUFACTURE

Roofing felts are produced by impregnating heavy papers with asphalt heated to about 400°F in tanks called saturators. As the sheets pass through the asphalt, droplets of oil distilled from the asphalt rise from the saturator. Prior to use in the saturators, the asphalt is subjected to high-pressure air at a rate of several hundred cubic feet per minute in blowing stills. This process results in emission of oil fumes. After the asphalt saturation operation, the roofing material is often covered with roofing granules, which may create a minor source of dust in the plant.

Particulate emission from asphalt air blowing has been reported as 3.9 pounds per ton of asphalt.[78] Oil mist emissions from three asphalt saturators averaged 65 pounds per hour and were seemingly independent of the size of the operation. Particle size is in the order of 1 micron.[79]

ASPHALTIC CONCRETE BATCH PLANTS

These plants are commonly called asphalt batch plants. An asphaltic concrete batching plant generally consists of a rotary dryer, screening and classifying equipment, an aggregate weighing system, a mixer, storage bins, and conveying equipment. Sand and aggregate are charged from bins into a rotary dryer. The dried aggregate at the lower end of the dryer is mechanically conveyed by a bucket elevator to the screening equipment where it is classified and dumped into storage bins. Asphalt and weighed quantities of the sized aggregate are then dropped into the mixer where the batch is mixed and then dumped

into trucks for transportation to the paving site. The combustion gases and fine dust from the rotary drier are exhausted through a precleaner. This is usually a single cyclone, but twin or multiple cyclones and other devices are also used. The precleaner catch is discharged back into the bucket elevator, where it continues in the process with the main bulk of the dried aggregate.

The exit gas stream of the precleaner usually passes through air pollution control equipment.[80] Table 25 details particulate emissions from uncontrolled and controlled asphalt batch plants. Particulate size distribution from uncontrolled plants is: about 3 percent greater than 44 microns , 20 percent 20 to 44 microns, 17 percent 10 to 20 microns, 25 percent 5 to 10 microns and 35 percent less than 5 microns.[80]

Table 25. PARTICULATE EMISSION FACTORS FOR ASPHALT BATCHING PLANTS[a]
(pounds per ton of product)

Control system	Particulate emission
Precleaner	5
High-efficiency cyclone	0.8
Multiple centrifugal scrubber	0.2
Baffle spray tower	0.2
Orifice-type scrubber	0.08
Baghouse	0.005

[a]References 47, 80, and 81.

CALCIUM CARBIDE PLANTS

In the manufacture of calcium carbide, lime and coke are charged to an electric arc furnace wherein lime is reduced by coke to calcium carbide and carbon monoxide. About 1,900 pounds of lime and 1,300 pounds of coke yield 1 ton of calcium carbide. The molten calcium carbide is poured into chill cars or bucket conveyors and allowed to solidify. The finished calcium carbide is dumped into a jaw crusher followed by a cone crusher to produce a product of desired size. About 75 percent of the total carbide production is used to make acetylene,

which is then used to make acetaldehyde, acetic acid, vinyl compounds, synthetic rubber, rayon, trichloroethylene, and cyanimide. At some plants calcium carbide is converted to acetylene by reaction with water.[82]

Acetylene, sulfur compounds, and particulates are emitted from the process. Table 26 contains emission data from one particular calcium carbide plant in which the materials from the hooded electric furnaces pass through impingement-type scrubbers before being vented to the atmosphere through a stack. The electric furnace hood provides additional ventilation directly to the atmosphere. The emissions from the furnace room vents are the material that escapes the other systems. No data on particle size were found in the literature.

Table 26. EMISSION FACTORS FOR CALCIUM CARBIDE PLANT[a]
(pounds per ton of product)

Pollutant	Coke drier[b]	Electric furnace hood	Furnace room vents	Main stack[c] (impingement scrubbers)
Acetylene	--	--	1.8	--
Sulfur trioxide	0.2	--	--	0.8
Sulfur dioxide	0.1	--	--	1.9
Particulate	0.2	1.7	2.6	2.0

[a]Reference 83.
[b]Equipped with cyclone and spray drier.
[c]Equipped with impingement scrubbers.

CEMENT MANUFACTURING PLANT

Raw materials for the manufacture of cement are ground, mixed, and blended by either a wet or a dry process. In the dry process, the moisture content of the raw materials does not exceed 1 percent; in the wet process, a slurry of carefully controlled composition is made, generally having a moisture content ranging from 30 to 50 percent. After the raw materials are crushed and ground, they are introduced into a rotary kiln that is fired with pulverized coal, oil, or gas to produce a temperature of about 2,700°F. In the kiln the materials are dried, decarbonated, and calcined to produce a cement clinker.

The clinker is cooled, mixed, ground with gypsum, and bagged for shipment as cement. Dust and fumes in the waste gases of the kiln are the major sources of air pollution.

Kiln emissions for the wet process of producing cement range from 15 to 55 pounds of dust per barrel of cement produced, with 38 pounds of dust per barrel of cement produced being a typical value. In the dry process, the losses range from 35 to 75 pounds of dust per barrel of cement produced, with 46 pounds of dust per barrel of cement being a typical value. Degree of control of kiln dust emissions depends largely upon the type and age of the control system. Typical collection efficiencies are: 80 percent for multicyclones, 90 percent for old electrostatic precipitators, 95 percent for multicyclones plus old electrostatic precipitator systems, greater than 99 percent for multicyclones plus new electrostatic precipitator systems, and greater than 99.5 percent for fabric filter units either alone or in combination with multicyclones.[84]

A typical size distribution of dust from cement kilns is: 8 percent greater than 44 microns, 20 percent 20 to 44 microns, 25 percent 10 to 20 microns, 25 per :ent 5 to 10 microns, and 22 percent less than 5 microns.[84]

CERAMIC AND CLAY PROCESSES

The ceramic and clay processing industries include manufacture of brick, tile, sewer pipe, pottery, vitreous wares, activated clay, catalysts, filter aids, and other related materials. Operations usually involve wet and dry fine grading, processing at high temperature in kilns or driers, and sometimes chemical treatment. Emission data are scarce in the literature. Particulate emissions are the primary atmospheric pollutant emitted from these processes. Fluorides have been emitted from processes using clays that contain fluoride.

In the manufacture of ceramic clay, a mixture of wet talc, whiting, silica clay, and other ceramic material is dried in an instant spray drier. Particulate emissions are reported as 15 pounds per ton of charge following a cyclone collector. Particulate emissions

from manufacture of bisque from crushed scrap tile is reported as 2 pounds per ton of charge following a dynamic centrifugal scrubber. Particulate emissions from a rotary drier, kiln, and cooler used in making catalytic material from clay emitted 6 pounds per ton of charge following a multiple-cyclone and spray-scrubber collection system.[74] There are many other processes in this industry for which no data were found. No actual particle size data have been reported.

CONCRETE BATCHING PLANT

Concrete batching plants are generally simple arrangements of steel hoppers, elevators, and batching scales for proportioning rock, gravel, and sand aggregates with cement for delivery, usually in in-transit mixer trucks. Aggregates are usually crushed and sized in separate plants and are delivered by truck or belt conveyors to ground or other storage from which they can be reclaimed and placed in the batch plant bunkers.

By careful use of sprays, felt, or other filter material over breathers in the cement silos and canvas curtains drawn around the cement dump trucks while dumping, dust losses can be controlled. Aggregate stocks in bunkers are wet down with sprays to prevent dusting. With careful operation under stringent standards like those applied in Los Angeles, losses in cement plants can be held to about 0.025 pound of dust per yard of concrete. Uncontroiled plants have emissions of about 0.2 pound of dust per yard of concrete handled.[74]

A typical size distribution of the dust from concrete batching indicates 14 percent greater than 44 microns, 25 percent 20 to 44 microns, 27 percent 10 to 20 microns, 21 percent 5 to 10 microns, and 13 percent less than 5 microns.[85]

FRIT MANUFACTURING PLANT

Frit is used in enameling iron and steel or in glazing porcelain and pottery. In a typical plant, the raw materials - consisting of a combination of materials such as borax, feldspar, sodium flouride or fluorspar, soda ash, zinc oxide, litharge, silica, boric acid, and zircon - are ground dry in pebble mills and then melted in small

reverberatory furnaces at about 2300°F. Enamel frit containing litharge is melted in oil-fired tilting furnaces. Exit gases contain particulate matter and some fluorides.

Particulate losses in the manufacture of frit consist primarily of condensed metallic fumes, which averaged about 16.5 pounds per ton of charge from six frit smelters ranging in size from 1,000 to 3,000 pounds capacity. Particle size distribution is about 10 percent greater than 44 microns, 15 percent 20 to 44 microns, 15 percent 10 to 20 microns, 15 percent 5 to 20 microns, and 45 percent less than 5 microns.[86]

Fluoride emissions from frit furnaces averaged 10 pounds, as fluorine, per ton of charge from two installations.[86]

A venturi scrubber with a 21-inch water gauge pressure drop had average collection efficiency of 67 percent for particulates and 94 percent for fluorides.[86]

GLASS MANUFACTURING PLANT

About 90 percent of the glass produced is manufactured by the soda-lime process. Major ingredients are sand, limestone, soda ash, and cullet. Soda-lime glass is produced in direct-fired continuous melting furnaces in which the blended raw materials are melted at 2700°F to form glass.

Emissions from the glass melting operation consist primarily of particulates and fluorides, if fluoride-containing fluxes are used in the process. Particulate emissions reportedly average about 2 pounds per ton of glass produced for good operation.[73] Fluoride emissions can be calculated on the basis of 20 percent of the input fluoride being emitted.[87] Particle size distribution for two installations averaged 1 percent 20 to 44 microns, 19 percent 10 to 20 microns, 55 percent 5 to 10 microns, and 25 percent less than 5 microns.

LIME MANUFACTURING PLANT

Lime is produced by calcining various types of limestone in continuous rotary or vertical kilns. The principal contaminant is particulate matter from the kiln and also from crushing, screening,

and conveying of the limestone. The dust generated by rotary lime kilns ranges from 5 to 15 percent by weight of the lime produced. Vertical kilns emit about 1 percent by weight of the lime produced.[89] About 28 percent of the particles are greater than 44 microns, 38 percent 20 to 44 microns, 24 percent 10 to 20 microns, 8 percent 5 to 10 microns, and 2 percent less than 5 microns.

Primary collection is usually accomplished with multiple cyclones, which reduce emissions from 65 to 85 percent by weight. Wet scrubbing systems report efficiencies from 95 to 98 percent. Venturi scrubbers have reported efficiency of 99 weight percent.[89, 90]

PERLITE MANUFACTURING PLANT

Perlite, a volcanic rock, consists of oxides of silicon and aluminum combined as a natural glass by water of hydration. By a process called exfoliation, the material is rapidly heated to release water of hydration and thus expand the spherules into low-density particles used primarily as aggregate in plaster and concrete. Vertical, horizontal stationary, and horizontal rotary furnaces are used for the exfoliation of perlite with vertical furnaces being the most numerous. Cyclone separators are used to collect the product.

Particulate emissions from a perlite expanding furnace are about 21 pounds per ton of charge.[91] Particle size following a cyclone precleaner is reported as 35 percent greater than 44 microns, 13 percent 20 to 44 microns, 10 percent 10 to 20 microns, 10 percent 5 to 10 microns, and 32 percent less than 5 microns.[92]

ROCK WOOL MANUFACTURING PLANT

Rock (mineral) wool is used mainly for thermal and acoustical insulation. The cupola or furnace charge is heated to a molten state at about 3000°F and then is fed to a blow chamber, where steam atomizes the molten rock into globules, which develop long fibrous tails as they are drawn to the other end of the chamber. The wool blanket formed is then conveyed to an oven to cure the binding agent and then to a cooler.

Particulate emissions from the cupola or reverberatory furnace consists primarily of condensed fumes with about 60 percent greater than 44 microns, 27 percent 20 to 44 microns, 10 percent 10 to 20 microns, 2.5 percent 5 to 10 microns, and 0.5 percent less than 5 microns. Particulate emissions from the blow chamber, curing oven, and cooler consist of about 90 percent mineral wool fibers varying from 5 to 7 microns in diameter and about 0.5 inch long. Table 27 details particulate emissions from the various uncontrolled mineral wool operations.[93]

Table 27. PARTICULATE EMISSIONS FROM MINERAL WOOL PROCESSES[a]
(pounds per ton of charge)

Cupola	21.6
Reverberatory furnace	4.8
Blow chamber	21.6
Curing oven	3.6
Cooler	2.4

[a]Reference 93.

ROCK, GRAVEL, AND SAND PROCESSING

Quarrying, crushing, screening, conveying, handling, and storage of various types of crushed rock and gravel create dust problems. Very little information is available on quantitative emission data from these operations. Particulate losses from crushing have been reported as 20 pounds per ton of product from a silicon carbide operation.[94] Conveying, screening, and sacking losses from a roofing-granule and poultry-grit rock sizing plant were found to be 1.7 pounds of particulate per ton of product. Particle size distribution from this operation was found to be 12 percent greater than 44 microns, 18 percent 20 to 44 microns, 20 percent 10 to 20 microns, 20 percent 5 to 10 microns, and 30 percent less than 5 microns.[95] Particle size distribution from a marble jaw crusher indicates 75 percent greater than 44 microns, 5 percent 10 to 20 microns, 5 percent 5 to 10 microns, and 5 percent less than 5 microns.[96] Storage pile losses due to wind erosion have been reported up to 1 percent of the product.[97]

PETROLEUM REFINERY

A modery refinery is a maze of equipment, but the entire operation can be discussed in terms of separation, conversion, treating, and blending. The crude oil is first separated into selected fractions (e.g., gasoline, kerosine, and fuel oil). Since the relative volumes of each fraction produced by merely separating the crude may not conform to the relative demand for each fraction, some of the less valuable separation products are converted to products with a greater sale value by splitting, combining, or rearranging the original molecules.

In the catalytic cracking operation, large molecules are decomposed into lower-boiling fractions by heat and pressure in the presence of catalysts. At the same time, some of the molecules combine to form larger molecules. The products of cracking are gaseous hydrocarbons, gasoline, kerosine, gas oil, fuel oil, and residual oil.

In catalytic reforming, gasoline is used as a feedstock; by molecular rearrangement, usually including hydrogen removal, gasoline of higher quality and octane number is produced. The types of reforming processes in use include fixed-bed systems with and without catalyst regeneration, and the fluidized processes.

Polymerization and alkylation are processes used to produce gasoline from the gaseous hydrocarbons formed from cracking operations. Polymerization joins two or more olefins, and alkylation unites an olefin and an isoparaffin. Insomerization is another process used. In this process the arrangement of the atoms in a molecule is altered, usually to form branched-chain hydrocarbons.

The products from both the separation and conversion steps are treated, usually for the removal of sulfur compounds and gum-forming materials. As a final step, the refined base stocks are blended with each other and with various additives to meet product specifications. Emission factors for petroleum refineries are given in Table 28.

Table 28. EMISSION FACTORS FOR PETROLEUM REFINERY[a]

Processes	Dimensions of emission factor	Emission factor
Boilers and process heaters	lb hydrocarbon/1000 bbl oil burned	140
	lb hydrocarbon/1000 ft^3 gas burned	0.026
	lb particulate/1000 bbl oil burned	800
	lb particulate/1000 ft^3 gas burned	0.02
	lb NO_2/1000 bbl oil burned	2,900
	lb NO_2/1000 ft^3 gas burned	0.23
	lb CO/1000 bbl oil burned	neg.
	lb CO/1000 ft^3 gas burned	neg.
	lb HCHO/1000 bbl oil burned	25
	lb HCHO/1000 ft^3 gas burned	0.0031
Fluid catalytic units	lb hydrocarbon/1000 bbl of fresh feed	220
	lb particulate/ton of catalyst circulation	0.10[b]
		0.018[c]
	lb NO_2/1000 bbl of fresh feed	63
	lb CO/1000 bbl of fresh feed	13,700
	lb HCHO/1000 bbl of fresh feed	19
	lb NH_3/1000 bbl of fresh feed	54
Moving-bed catalytic cracking units	lb hydrocarbon/1000 bbl of fresh feed	87
	lb particulate/ton of catalyst circulation	0.04[d]
	lb NO_2/1000 bbl of fresh feed	5
	lb CO/1000 bbl of fresh feed	3,800
	lb HCHO/1000 bbl of fresh feed	12
	lb NH_3/1000 bbl of fresh feed	5
Compressor internal combustion engines	lb hydrocarbons/1000 ft^3 of fuel gas burned	1.2
	lb NO_2/1000 ft^3 of fuel gas burned	0.86
	lb CO/1000 ft^3 of fuel gas burned	neg.
	lb HCHO/1000 ft^3 of fuel gas burned	0.11
	lb NH_3/1000 ft^3 of fuel gas burned	0.2
Miscellaneous process equipment	lb hydrocarbon/1000 bbl refinery capacity	
Blowdown system		
With control		5
Without control		300
Process drains	lb hydrocarbon/1000 bbl waste water	
With control		8
Without control		210
Vacuum jets	lb hydrocarbon/1000 bbl vacuum distillation capacity	
With control		neg.
Without control		130
Cooling towers	lb hydrocarbon/1,000,000 gal cooling water capacity	6
Pipeline valves and flanges	lb hydrocarbon/1000 bbl refinery capacity	28
Vessel relief valves	lb hydrocarbon/1000 bbl refinery capacity	11
Pump seals	lb hydrocarbon/1000 bbl refinery capacity	17
Compressor seals	lb hydrocarbon/1000 bbl refinery capacity	5
Others (air blowing, blend changing, and sampling)	lb hydrocarbon/1000 bbl refinery capacity	10

[a]Reference 98.

[b]Without electrostatic precipitator.

[c]With electrostatic precipitator.

[d]With high-efficiency centrifugal separator.

PULP AND PAPER INDUSTRY

Before the cellulose from wood can be made into pulp, the lignin that binds the cellulose fibers together must be removed. In the kraft process, this is done by treating with an aqueous solution of sodium sulfide and sodium hydroxide. This liquor is mixed with wood chips in a large upright pressure vessel, called a digester, and cooked for about 3 hours with steam. During the cooking period, the digester is relieved periodically to reduce the pressure buildup of gases.

When cooking is completed, the bottom of the digester is suddenly opened, and its contents forced into the blow tank. Here, the major portion of the spent cooking liquor, containing the dissolved lignin, is drained, and pulp enters the initial stage of washing. From the blow tank the pulp passes through the knotter, where unreacted chunks of wood are removed. The pulp is then processed through intermittent stages of washing and bleaching, after which it is pressed and dried into the finished product.

Most of the chemicals from the spent cooking liquor are recovered for reuse in subsequent cooks. The spent "black" liquor from the blow tank is concentrated first in the multiple-effect evaporator and then in a direct-contact evaporator utilizing recovery furnace flue gases.

The combustible, concentrated, black liquor thus produced is burned in a recovery furnace, where the inorganic chemicals to be recovered fall to the floor of the furnace in a molten state.

The melt, consisting mainly of sodium sulfide and sodium carbonate, is withdrawn from the furnace and dissolved with water and weak causticizing plant liquor in a smelt tank. The "green" liquor thus produced is pumped into a causticizer wherein the sodium carbonate is converted to sodium hydroxide by the addition of calcium hydroxide. The calcium carbonate produced is converted into calcium

oxide in a lime kiln, and is slaked to produce calcium hydroxide for further use in the causticizer. The effluent solution produced by the causticizing reaction is known as "white" liquor and is withdrawn and reused in the digestion process.

Table 29 summarizes the emissions from the various processes involved in a kraft pulp mill.[99, 100]

Table 29. EMISSION FACTORS FOR KRAFT PULP[a]

(pounds per ton of dry pulp produced)

Source	Hydrogen sulfide	Methyl mercaptan	Dimethyl sulfide	Particulate pollutants	Type of control
Digester blow system	0.1-0.7	0.9-5.3	0.9-3.8	Neg.	Untreated
Smelt tank	n.a.[b]	n.a.[b]	n.a.[b]	20 5 1-2	Uncontrolled Water spray Mesh demister
Lime kiln	1	Neg.	Neg.	18.7	Scrubber (approximately 80% efficient)
Recovery furnace[c]	3.6 3.6-7.0 0.7	5 n.a.[b] n.a.[b]	3 n.a.[b] n.a.[b]	150 7-16 12-25	Primary stack gas scrubber Electrostatic precipitator Venturi scrubber
Multiple-effect evaporator	1.2 0-0.5	0.04 0.003-0.030	n.a.[b] Neg.	Neg. Neg.	Untreated Black liquor oxidation
Oxidation towers	n.a.[b]	n.a.[b]	0.1	Neg.	Black liquor oxidation

[a]References 99, and 100.

[b]Not available.

[c]Gaseous sulfurous emissions are greatly dependent on the oxygen content of the flue gases and furnace operating conditions.

SOLVENT EVAPORATION AND GASOLINE MARKETING

DRY CLEANING PLANTS

Almost all dry cleaning is performed with three solvents: tetrachloroethylene, Stoddard solvent, and safety 140°F solvent. Stoddard solvent has a minimum flash point of 100°F and a distillation range within 100° to 410°F. Safety 140°F solvent has a minimum flash point of 140°F, thus lessening the explosion hazard.

Chlorinated hydrocarbons are widely used as cleaning solvents. They are nonflammable and dissolve greases and oils rapidly, including substances not soluble in petroleum solvents. Tetrachloroethylene (perchlorethylene) is the most widely used chlorinated dry cleaning agent. Because it is expensive and a health hazard, tetrachloroethylene is often recovered by use of carbon adsorption beds.

Table 30 gives emission factors for chlorinated and nonchlorinated hydrocarbon dry cleaning solvents based upon data received from three different areas.[101, 102]

SURFACE-COATING OPERATIONS

Organic solvent is lost from surface-coating operations as a result of evaporation and vaporization during the spraying application and the subsequent baking or drying. Spraying and other surface-coating operations are generally uncontrolled, thus the solvent vapors are released to the atmosphere. Some of the industries involved in surface-coating operations are automobile assemblies, aircraft companies, container manufacturers, furniture manufacturers, appliance manufacturers, job enamelers, automobile repainters, and plastic products manufacturers. All solvents consumed in surface coating are normally released to the atmosphere.[103]

Table 30. EMISSION FACTORS FOR DRY CLEANING PLANTS[a]

	Los Angeles,[b] January 1963	Kent County,[c] Michigan, 1965	BAAPCD[d] 1963
Chlor-hydrocarbons emitted, tons/day	15	0.3	7.9
Petroleum solvents emitted, tons/day	20	0.7	11.5
Total	35	1	19.4
Clothes cleaned/capita, lb/yr	18	25.1	18.3
Chlor-hydrocarbons emitted/capita, lb/yr	1.7	1.8	1.5
Hydrocarbon vapors emitted/capita, lb/yr	2.2	2.2	2.3
Total organic solvents emitted/capita, lb/yr	3.9	4.0	3.8

[a] References 101 and 102.
[b] Los Angeles County Air Pollution Control District data; population covered, 6,492,000.
[c] Kent County, Michigan, data; population covered, 363,167.
[d] San Francisco Bay Area Air Pollution Control District data; population covered, 3,691,000.

GASOLINE MARKETING

A study of the typical pattern of motor gasoline storage and handling reveals five major points of gasoline emission:

1. Breathing and filling losses from storage tanks at refineries and bulk terminals.

2. Filling losses from loading tank conveyances at refineries and bulk terminals.

3. Filling losses from loading underground storage tanks at service stations.

4. Spillage and filling losses in filling automobile gas tanks at service stations.

5. Evaporative losses from the carburetor and gas tank of motor vehicles.

Breathing loss has been defined as the loss associated with the thermal expansion and contraction of the vapor space resulting from the daily temperature cycle. Filling loss has been defined as the vapors expelled from a tank (by displacement) as a result of filling.[104]

Splash and submerged fill have been defined by R. L. Chass, et al.,[105] as follows: "In splash fill the gasoline enters the top of the fill pipe and then has a free fall to the liquid surface in the tank. The free falling tends to break up the liquid stream into droplets. As these droplets strike the liquid surface, they carry entrained air into the liquid, and a (boiling) action results as this air escapes up through the liquid surface. The net effect of these actions is the creation of additional vapors in the tank. In submerged filling, the gasoline flows to the bottom of the tank through the fill pipe and enters below the surface of the liquid. This method of filling creates very little disturbances in the liquid bath and, consequently, less vapor formation than splash filling."

Emission factors are given for both cone-roof and floating-roof storage tanks, as well as for splash and submerged fill in tank vehicles and service station tanks. The degree to which floating roof tanks and submerged fill are utilized varies from place to place. Ideally, the gasoline evaporative emissions should be calculated on the basis of the percentage of local utilization of submerged fill and floating-roof tanks. If this is not known, then 75 percent floating-roof tanks and 50 percent submerged fill should be assumed. The effect of vapor-recovery loading arms or tank compression systems has not been considered.

An average emission factor for hydrocarbons from uncontrolled cone-roof gasoline storage tanks is 47 pounds per day per 1,000 barrels of storage capacity. For floating-roof tanks storing gasoline, a typical hydrocarbon emission is 4.8 pounds per day per 1,000 barrels of storage capacity.[104] Table 31 summarizes the emission factors for gasoline evaporation at the other four points of emission.

Table 31. GASOLINE EVAPORATION EMISSION[a]

Point of emission	lb/1000 gal of throughput	Percent emission losses, by volume[b]
Filling tank vehicles		
Splash fill	8.2	0.14
Submerged fill	4.9	0.08
50% splash fill and 50% submerged fill	6.4	0.11
Filling service station tanks		
Splash fill	11.5	0.19
Submerged fill	7.3	0.12
50% splash fill and 50% submerged fill	9.4	0.15
Filling automobile tanks	11.6	0.19
Automobile evaporation losses (gas tank and carburetor)	92	1.50

[a]References 105, 106, 107, and 108.
[b]An average gasoline specific gravity of 0.73 is assumed.

TRANSPORTATION

Air contaminant emissions from mobile sources are similar to those from other combustion sources, but tend to emit larger quantities of carbon monoxide and organic matter. They emit significant quantities of oxides of nitrogen and also particulate matter. The following sections detail air pollutant emissions from aircraft, automobiles, and diesel trucks and buses.

AIRCRAFT

Emissions are presented for the three major types of commercial aircraft: jet, turboprop, and piston-powered engines.* Emission factors are presented on the basis of pounds per flight where a flight is a combination of a landing and a take-off. These factors, shown in Table 32, are combined and averaged figures for emissions during all

Table 32. EMISSION FACTORS FOR AIRCRAFT BELOW 3,500 FEET[a]
(pounds per flight)[b]

Types of emission	Jet aircraft, four engine[c, d]		Turboprop aircraft		Piston-engine aircraft	
	Conventional	Fan-Jet	Two engine	Four engine	Two engine	Four engine
Aldehydes (HCHO)	4	2.2	0.3	1.1	0.4	1.0
Carbon monoxide	35	20.6	2.0	9.0	268.0	652.0
Hydrocarbons (C)	10	29.0	0.3	1.2	50.0	120.0
Oxides of nitrogen (NO_2)	23	9.2	1.1	5.0	12.6	30.8
Particulates	34	7.4	0.6	2.5	1.2	2.8

[a] References 110, 111, and 112.

[b] A flight is defined as a combination of a landing and a take-off.

[c] No water injection on take-off.

[d] For three-engine aircraft, multiply these data by 0.75 and for two-engine aircraft, multiply these data by 0.5.

*For additional discussion of this subject, see Senate Document 91-9, Nature and Control of Aircraft Engine Exhaust Emissions, Report of the Secretary of Health, Education, and Welfare to the United States Congress, December 1968.

phases of aircraft operation (taxi - take-off, climb-out, approach, and landing) that take place below the arbitrarily chosen altitude of 3,500 feet. Emissions at cruise altitude (above 3,500 feet) are not of concern in conducting an emission inventory.

Data were obtained for fuel consumption in the three major classes of aircraft so that emissions may be calculated in terms of pounds per gallon of fuel consumed. Four-engine jet aircraft use about 630 gallons; four-engine turboprops about 625 gallons; four-engine pistons about 234 gallons; and two-engine pistons about 96 gallons per flight. A flight is the combination of a landing and a takeoff.

Electron micrographs of aircraft exhaust particulates are very similar to those from automobiles. These particulates can be assumed to be all less than 5 microns.[113]

AUTOMOBILES

Automobile exhaust gases are the major source of hydrocarbons, oxides of nitrogen, and carbon monoxide emissions to the atmosphere in our metropolitan areas. Controls have been developed to reduce hydrocarbon and carbon monoxide emissions. These controls have been installed on new model cars in California since 1966 and will be installed on new cars throughout the nation beginning with the 1968 model year.

Table 33 presents emission factors for uncontrolled automobile exhaust. These factors are expressed in three different ways to

Table 33. EMISSION FACTORS FOR AUTOMOBILE EXHAUST[a]

Type of emission	Emissions		
	pounds per 1000 vehicle-miles	pounds per 1000 gallons of gas	pounds per vehicle-day
Aldehydes (HCHO)	0.3	4	0.007
Carbon monoxide	165.0	2300	4.160
Hydrocarbons (C)	12.5	200	0.363
Oxides of nitrogen (NO_2)	8.5	113	0.202
Oxides of sulfur (SO_2)	0.6	9	0.016
Organic acids (acetic)	0.3	4	0.007
Particulates	0.8	12	0.022

[a]References 83, 114, 115, and 116.

facilitate calculations in emission inventories. These are average emission factors based upon an average route speed of 25 miles per hour in urban areas.[116]

A representative urban vehicle is estimated to drive 3.25 trips per day of 8 miles in length each.[116] The average automobile travels about 14.4 miles per gallon of gasoline consumed.[118]

Emissions from automobiles are highly variable, depending upon geographical location and local driving patterns. In high-altitude cities, as measured in Denver, Colorado, hydrocarbon emissions are 30 percent greater, carbon monoxide 60 percent greater, and oxides of nitrogen 50 percent less than those in low-altitude cities, as measured in Cincinnati and Los Angeles.[111] To account for differences in local traffic patterns, emissions of hydrocarbons and carbon monoxide may be calculated from the data presented in Table 34, which gives carbon monoxide and hydrocarbon emissions for various average route speeds and types of roads. Oxides of nitrogen are not dependent upon route speed, but upon fuel-to-air ratio, which averages about 12.8.[116]

Table 34. EMISSION FACTORS FOR AUTOMOBILE EXHAUST[a]
(pound per vehicle-mile)

Route type	Average route speed, mph	Hydrocarbons[b]	Carbon monoxide
Business	10	0.023	0.35
Residential	18	0.015	0.21
Arterial	24	0.013	0.17
Rapid transit	45	0.0085	0.10

[a]Reference 119.

[b]Expressed as carbon as measured by flame ionization detector.

Road tests conducted in five cities on 1966 automobiles equipped with exhaust control devices indicated a 35 percent reduction in hydrocarbons, 67 percent reduction in carbon monoxide, and a 26 percent increase in oxides of nitrogen emissions. In the high-altitude city (Denver), hydrocarbons decreased 46 percent, carbon monoxide decreased 47 percent, and oxides of nitrogen increased 241 percent.[120]

Another source of hydrocarbon emissions, if uncontrolled, is

the engine crankcase blowby. Hydrocarbon emissions from an uncontrolled vehicle is about 0.2 pound per vehicle-day. Since 1963 essentially all new cars throughout the Nation have been equipped with crankcase blowby control systems, which have been approximately 90 percent effective in reducing hydrocarbon emissions.[116] Fuel evaporative emissions from the automobile are covered in the gasoline marketing section of this report.

Particulate emissions from automobiles consist of carbon particles, lead compounds, motor oil, and nonvolatile reaction products formed in the combustion zone from motor oil. Particulates emitted from the exhaust are essentially all less than 5 microns in size.[121] Automobiles, however, contribute significantly to particulate pollution problems, since aerosols are formed in the reaction products from hydrocarbons and oxides of nitrogen in the photochemical reaction.[122]

DIESEL ENGINE VEHICLES

Emissions from diesel engine vehicles can be calculated from data presented in Table 35. Note that emissions of carbon monoxide and hydrocarbons are lower; but emissions of nitrogen oxides, aldehydes, oxides of sulfur, organic acids, and particulates are higher than the corresponding emissions from the gasoline engine.

Particle size from diesel exhaust is estimated as 62.5 percent less than 5 microns and 37.5 percent 5 to 20 microns.[124] No control systems have been developed for diesel exhaust emissions.

Table 35. EMISSION FACTORS FOR DIESEL ENGINES[a]
(pounds per 1,000 gallons of diesel fuel)

Type of emission	Emission factor
Aldehydes (HCHO)	10
Carbon monoxide	60
Hydrocarbons (C)	136
Oxides of nitrogen (NO_2)	222
Oxides of sulfur	40
Organic acids (acetic)	31
Particulate	110

[a]References 83, 122, and 123.

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APPENDICES

A. PARTICULATE CONTROL EQUIPMENT

In the process of conducting an emissions inventory, the collection efficiency for controlled sources of air pollution must sometimes be determined. Where possible this information has been included in the report for the specific source and application of control equipment. Since this information is not complete, information in this section on particulate control equipment can be used to determine collection efficiency in those cases where applicable data are not available.

Table A-1 presents collection efficiency data for particulate control equipment. These data have been based on a standard silica

Table A-1. COLLECTION EFFICIENCY OF PARTICULATE CONTROL EQUIPMENT[a]

Collector type	Efficiency, %					
	Overall	0-5	5-10	10-20	20-44	>44
Baffled settling chamber	58.6	7.5	22	43	80	90
Simple cyclone	65.3	12	33	57	82	91
Long-cone cyclone	84.2	40	79	92	95	97
Multiple cyclone - 12-in. diameter	74.2	25	54	74	95	98
Multiple cyclone - 6-in. diameter	93.8	63	95	98	99.5	100
Irrigated long-cone cyclone	91.0	63	93	96	98.5	100
Electrostatic precipitator	97.0	72	94.5	97	99.5	100
Irrigated electrostatic precipitator	99.0	97	99	99.5	100	100
Spray tower	94.5	90	96	98	100	100
Self-induced spray scrubber	93.6	85	96	98	100	100
Disintegrator scrubber	98.5	93	98	99	100	100
Venturi scrubber, 30-in. pressure drop	99.5	99	99.5	100	100	100
Wet impingement scrubber	97.9	96	98.5	99	100	100
Baghouse	99.7	99.5	100	100	100	100

[a]References 125 and 126.

dust with a particle density of 2.7 grams per cubic foot and with the following particle size distribution:

Particle size range, microns	Percent by weight
0-5	20
5-10	10
10-20	15
20-44	20
> 44	35

This standard dust is similar to that from coal-fired furnaces. These are based upon proper design and installation, and thus collection efficiencies are probably optimistic in terms of actual practice in some instances.

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CHANGES TO

NAPCA PUBLICATION NO. AP-42

COMPILATION OF AIR POLLUTANT EMISSION FACTORS

P. 5, Table 3 - Change NO_4 to NO_2

P. 6, Table 4 - Change Reference 2 to References 2 and 4

P. 7, Table 5 - Residual oil refers to NBS Commercial Standards grades 4, 5, and 6. Distillate oil refers to grades 1 and 2.

P. 11, Table 9 - Hexane should be changed to methane, and hydrocarbon emission factors from 5, 2, and 5 to 30, 12, and 30, respectively.

P. 24, 26, 28 - Emission factors for copper, lead, and zinc smelters are:

Copper Smelting - primary	1400	lb of SO_2 / ton of concentrated ore
Lead Smelting - primary	660	lb of SO_2 / ton of concentrated ore
Zinc Smelting - primary	1090	lb of SO_2 / ton of concentrated ore

P. 29, Table 19 - Change uncontrolled emission factor for sweating furnace from 32.2 to 14.5.

P. 49, Table 32 - Change hydrocarbon emission factor for fan-jet aircraft from 19.0 to 29.0. Multiply all emission factors for piston-engine aircraft by 2. For additional discussion of this subject, see Senate Document 91-9, Nature and Control of Aircraft Engine Exhaust Emissions, Report of the Secretary of Health, Education, and Welfare to the United States Congress, December 1968, particularly, Table 5, page 16.

P. 50 - Multiply gasoline consumption data for piston-engine aircraft by 2. For additional discussion of this subject, see Senate Document 91-9, Nature and Control of Aircraft Engine Exhaust Emissions, Report of the Secretary of Health, Education, and Welfare to the United States Congress, December 1968, particularly, Table 4, page 15.

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